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Process for the preparation of mono- and bis(fluoroalkyl)phosphoranes
and the corresponding acids and phosphates

5 The present invention relates to a process for the preparation of mono-
(fluoroalkyl)- or bis(fluoroalkyl)phosphoric acids, mono(fluoroalkyl) or bis-
(fluoroalkyl) phosphates and the corresponding phosphoranes thereof.

10 A process known from the prior art for the synthesis of fluoroalkylphos-
phoranes is based on the electrochemical Simons fluorination (ECF) of
alkylphosphines (N. Ignatyev, P. Satori, *J. of Fluorine Chem.*, 103 (2000)
57-61; WO 00/21969) and, owing to the high yields, is particularly suitable
for the synthesis of tris(fluoroalkyl)difluorophosphoranes. In the electro-
chemical fluorination of dialkylphosphines having short alkyl chains (having
15 less than C₄), the yield of the corresponding perfluorinated phosphoranes
is significantly lower.

20 The tris(fluoroalkyl)difluorophosphoranes can be used as starting materials
for the synthesis of various phosphates (WO 98/15562, DE 196 41 138,
EP 1 127 888) and a novel tris(fluoroalkyl)trifluorophosphoric acid
(DE 101 30 940). This acid can be used not only for the synthesis of vari-
ous salts, but can also be hydrolysed to give the corresponding bis(fluoro-
alkyl)phosphinic acid (DE 102 169 97). Bis(fluoroalkyl)phosphinic and
25 fluoroalkylphosphonic acid and salts thereof can also be obtained by
hydrolysis of tris(fluoroalkyl)difluorophosphoranes (DE 102 169 95).

30 A process known from the prior art for the preparation of mono(perfluoro-
alkyl)- and bis(perfluoroalkyl)fluorophosphoranes is furthermore a multistep
reaction based on the reaction between phosphorus and perfluoroalkyl
halides, which are very expensive (T. Mahmood, J.M. Shreeve, *Inorg.*
Chem., 25 (1986) 3128). This reaction frequently requires high pressures
35 and temperatures.

Trifluoromethylphosphorane is formed in the reaction of $(\text{CF}_3)_2\text{Cd}$ with PF_5 or PCl_5 (R. Eujen, R. Haiges, Z. Naturforsch., 53b (1998) 1455). However, tris(trifluoromethyl)phosphorane is preferentially formed in this reaction, while CF_3PF_4 and $(\text{CF}_3)_2\text{PF}_3$ have only been detected by NMR spectroscopy in the reaction mixture. A further disadvantage of this reaction is the use of the unstable donor-free $(\text{CF}_3)_2\text{Cd}$, which has to be prepared from expensive CF_3I in a number of steps.

Mono(pentafluorophenyl)- and bis(pentafluorophenyl)fluorophosphoranes can be prepared in a multistep reaction, in which the first step is a reaction of pentafluorophenylmagnesium bromide with PCl_3 (M. Fild, O. Glemser, I. Hollenberg, Z. Naturforsch., 21b (1966) 920; D.D. Magnelly, G. Tesi, J.U. Lowe, W.E. McQuistion, Inorg. Chem., 5 (1966) 457; R.M.K. Deng, K.B. Dillon, W.S. Sheldrick, J. Chem. Soc. Dalton Trans. 1990, 551) or with PBr_3 (A.H. Cowley, R.P. Pinnell, J. Am. Chem. Soc. 88 (1966) 4533; R. Ali, K.B. Dillon, J. Chem. Soc. Dalton Trans. 1990, 2593). The resultant mixture of mono(pentafluorophenyl)- and bis(pentafluorophenyl)chloro- or -bromophosphine can be separated by fractional distillation, and the corresponding fluorophosphoranes are formed by reaction with Cl_2 and subsequent reaction with AsF_3 or SbF_3 (M. Fild, R. Schmutzler, J. Chem. Soc. (A) 1969, 840).

Furthermore, the prior art describes some syntheses of mono(pentafluoroethyl) and bis(pentafluoroethyl) fluorophosphates, but these are all based on very expensive starting materials and therefore cannot be carried out economically (for example N.V. Pavlenko, L.M. Ygupolskii, Zh. Org. Khim (russ.) 59 (1989) 528; S.S. Chan, C.J. Willis, Can. J. Chem. 46 (1968) 1237; J. Jander, D. Börner, U. Engelhardt, Liebigs Ann. Chem., 726 (1969) 19).

The object of the present invention is to indicate an industrial and economically advantageous process for the preparation of mono(fluoroalkyl) and bis(fluoroalkyl) phosphates and the corresponding phosphoranes thereof

which has, in particular, good yields and is simpler and less expensive than the processes known from the prior art.

5 This object is achieved in accordance with the invention by the characterising features of the main claim and the coordinated claims.

10 The invention is distinguished by the fact that bis(fluoroalkyl)phosphinic or fluoroalkylphosphonic acid or salts or derivatives thereof form the corresponding fluoroalkylphosphoric acids by simple reaction with anhydrous hydrogen fluoride (HF) with subsequent salt formation or form the fluoroalkyl phosphates directly in good yields. The mono(fluoroalkyl) or bis(fluoroalkyl) phosphates can then be converted into the corresponding phosphoranes by treatment with strong electrophilic reagents or strong
15 Lewis acids.

For the purposes of the present invention, mono(fluoroalkyl) and bis(fluoroalkyl) phosphates are compounds in which the phosphorus carries five or four fluorine atoms in addition to the one or two fluoroalkyl groups. The
20 mono- and bis(fluoroalkyl) phosphates prepared in accordance with the invention are therefore mono(fluoroalkyl) pentafluorophosphates and bis(fluoroalkyl) tetrafluorophosphates. The corresponding phosphoranes prepared in accordance with the invention accordingly contain respectively
25 four or three fluorine atoms which are bonded directly to the phosphorus atom. For the purposes of the present invention, fluoroalkyl groups are straight-chain or branched alkyl or cycloalkyl groups which are fluorinated and which contain no, one, two or three double bonds.

30 Fluorinated alkyl groups are, for example, difluoromethyl, trifluoromethyl, pentafluoroethyl, pentafluoropropyl, heptafluoropropyl, pentafluorobutyl, heptafluorobutyl, nonafluorobutyl, $C_5H_4F_7$, $C_5H_2F_9$, C_5F_{11} , $C_6H_4F_9$, $C_6H_2F_{11}$,
35 C_6F_{13} , $C_7H_4F_{11}$, $C_7H_2F_{13}$, C_7F_{15} , $C_8H_4F_{13}$, $C_8H_2F_{15}$, C_8F_{17} , $C_9H_4F_{15}$, $C_9H_2F_{17}$, C_9F_{19} , $C_{10}H_4F_{17}$, $C_{10}H_2F_{19}$, $C_{10}F_{21}$, $C_{11}H_4F_{19}$, $C_{11}H_2F_{21}$, $C_{11}F_{23}$,

$C_{12}H_4F_{21}$, $C_{12}H_2F_{23}$ or $C_{12}F_{25}$. Perfluoroalkyl group means that all H atoms of the alkyl group, as described above, have been replaced by F atoms.

The fluorinated alkyl groups may furthermore contain one, two or three double bonds, for example correspondingly fluorinated allyl, 2- or 3-butenyl, isobutenyl, sec-butenyl, furthermore 4-pentenyl, isopentenyl, hexenyl, heptenyl, octenyl, $-C_9H_{17}$, $-C_{10}H_{19}$ to $-C_{20}H_{39}$.

Fluorinated means that 1 to 4 fluorine atoms in a perfluoroalkyl or perfluorocycloalkyl group have been replaced by hydrogen atoms.

Cycloalkyl groups is taken to mean, for example, saturated or partially or fully unsaturated cycloalkyl groups having 3-7 C atoms, such as cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, cycloheptyl, cyclopentenyl, cyclopenta-1,3-dienyl, cyclohexenyl, cyclohexa-1,3-dienyl, cyclohexa-1,4-dienyl, phenyl, cycloheptenyl, cyclohepta-1,3-dienyl, cyclohepta-1,4-dienyl or cyclohepta-1,5-dienyl, which are correspondingly fluorinated and which may be substituted by C_1 - to C_6 -alkyl groups, where the cycloalkyl group and the cycloalkyl group substituted by C_1 - to C_6 -alkyl groups are themselves fluorinated.

The process according to the invention for the preparation of mono- or bis(fluoroalkyl) phosphates and the corresponding phosphoranes thereof thus comprises at least the reaction of a bis(fluoroalkyl)phosphinic acid or a (fluoroalkyl)phosphonic acid or a corresponding derivative of these acids with anhydrous hydrogen fluoride.

The bis(fluoroalkyl)phosphinic acids and the (fluoroalkyl)phosphonic acids and the corresponding derivatives of these acids can be prepared by conventional methods known to the person skilled in the art. These compounds are preferably prepared by hydrolysis of tris(fluoroalkyl)phosphine oxides, tris-, bis- or mono(fluoroalkyl)phosphoranes, tris-, bis- or mono(fluoroalkyl)phosphoric acids or anhydrides or haloanhydrides of bis(fluoroalkyl)phosphinic acids and (fluoroalkyl)phosphonic acids (cf., for example, DE 102 169 97 and DE 102 169 95) or by reaction of these compounds

with alcohols or alkoxides or amines. The esters of fluoroalkylphosphonic acids containing double bonds in the carbon chain can be prepared, for example, by reaction of perfluoroolefins with trialkyl phosphites (Knunjanz et al., Dokl. Akad. Nauk. SSR, 129 (1959) 576-577). The corresponding descriptions are hereby incorporated by way of reference and are regarded as part of the disclosure.

Mixtures of two or more bis(fluoroalkyl)phosphinic acids and/or two or more (fluoroalkyl)phosphonic acids and/or two or more corresponding derivatives of these acids can also be used in accordance with the invention. Preferably, only one bis(fluoroalkyl)phosphinic acid or (fluoroalkyl)phosphonic acid or corresponding derivative of these acids is in each case reacted in the process according to the invention.

The bis(fluoroalkyl)phosphinic acids used in accordance with the invention or the corresponding derivatives thereof have two fluoroalkyl groups, as described above, which are identical or different. Preference is given to the use of bis(fluoroalkyl)phosphinic acids or the corresponding derivatives thereof containing identical fluoroalkyl groups in each case.

In a preferred embodiment of the process according to the invention, use is made of a bis(perfluoroalkyl)phosphinic acid or a (perfluoroalkyl)phosphonic acid or a corresponding derivative of these acids in which the perfluoroalkyl groups contain 1 to 20 C atoms and are straight-chain or branched. Particular preference is given to starting materials whose perfluoroalkyl groups have 1 to 12 C atoms, as described above. Very particular preference is given to pentafluoroethyl, nonafluorobutyl or perfluoroprop-1-enyl.

The preferred derivative of bis(fluoroalkyl)phosphinic acid or (fluoroalkyl)phosphonic acid employed for the process according to the invention is a salt with a mono-, di- or trivalent metal cation. The metal cations which are

particularly preferred in accordance with the invention are selected from the group Li^+ , Na^+ , K^+ , Mg^{2+} , Ca^{2+} , Ba^{2+} , Zn^{2+} , Cu^{2+} or Al^{3+} .

Alternatively, the preferred derivative of bis(fluoroalkyl)phosphinic acid or (fluoroalkyl)phosphonic acid employed for the process according to the invention is a salt with a mono- or divalent organic cation. Particular preference is given to organic cations which contain at least one nitrogen atom and/or are cyclic. The organic cations which are very particularly preferred in accordance with the invention are selected from the group tetraalkylammonium, tetraalkylphosphonium, triarylalkylphosphonium, guanidinium, pyrrolidinium, pyridinium, imidazolium, piperazinium or hexamethylenediammonium.

Furthermore, the derivative of bis(fluoroalkyl)phosphinic acid or (fluoroalkyl)phosphonic acid employed for the process according to the invention is a salt with a polycation. This polycation is particularly preferably in accordance with the invention a polyammonium cation, for example protonated polyethylenimines.

Suitable as further preferred derivative for the process according to the invention are the esters of bis(fluoroalkyl)phosphinic acid or (fluoroalkyl)phosphonic acid. The mono(fluoroalkyl)- or bis(fluoroalkyl)phosphoric acids are formed first and can then be converted into the corresponding phosphates by salt formation. Processes for salt formation are adequately known to the person skilled in the art, for example the reaction of phosphoric acid with a chloride, bromide, iodide, methylsulfonate, methylsulfate, perchlorate, tetrafluoroborate, acetate, trifluoromethylcarboxylate, trifluoromethylsulfonate or carbonate, preferably with a chloride, bromide, methylsulfonate or trifluoromethylsulfonate and one of the cations as described above.

5 A suitable reaction medium for the process according to the invention is a conventional polar solvent known to the person skilled in the art. Alternatively, the process according to the invention can also be carried out without a solvent, i.e. in anhydrous hydrogen fluoride. Without restricting generality, the polar solvent used is particularly preferably dichloromethane, diethyl ether, diethyl carbonate, dioxane or a mixture thereof; immediately after the reaction with anhydrous HF, the solvents used can also be water or alcohols.

10 The temperature at which the reaction is preferably carried out in accordance with the invention is between -20°C and 100°C. The reaction is particularly preferably carried out at a temperature of 0°C to room temperature.

15 In a preferred variant of the process according to the invention, a 4- to 100-fold amount of hydrogen fluoride is used, based on the molar amount of the bis(fluoroalkyl)phosphinic acid or the (fluoroalkyl)phosphonic acid or the corresponding derivative of these acids. Particular preference is given to a 5- to 25-fold molar amount of hydrogen fluoride.

20 In a further embodiment of the process according to the invention, the mono- or bis(fluoroalkyl) phosphate formed after the reaction with hydrogen fluoride is reacted with a strong electrophilic reagent or a strong Lewis acid.

25 The choice of a suitable electrophilic reagent or Lewis acid presents the person skilled in the art with absolutely no difficulties. The electrophilic reagent or Lewis acid employed in accordance with the invention is particularly preferably (CH₃)₃SiCl, SO₂Cl₂, SbF₅, AlCl₃, VF₅, SbCl₅, NbF₅, AsF₅, BiF₅, AlF₃, TaF₅ or a mixture thereof.

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5 The process according to the invention is advantageously a one-step process, which can be carried out inexpensively and simply. In addition, the use of expensive reagents can be avoided; thus, for example, HF can be employed instead of SF₄ and AlCl₃ can be employed instead of Cl₂ + SbF₃.

10 The complete disclosure content of all applications, patents and publications mentioned above and below is incorporated into this application by way of reference.

15 Even without further comments, it is assumed that a person skilled in the art will be able to utilise the above description in the broadest scope. The preferred embodiments and examples should therefore merely be regarded as descriptive disclosure which is absolutely not limiting in any way.

20 The NMR spectra were measured in solutions in deuterated solvents at 20°C in a Bruker Avance 300 spectrometer with a 5 mm ¹H/BB broad-band head with deuterium lock. The measurement frequencies of the various nuclei are: ¹H: 300.13 MHz, ¹⁹F: 282.41 MHz and ³¹P: 121.49 MHz. The referencing method is indicated separately for each spectrum or for each data set.

25 Examples:

Example 1:
30 5.364 g (17.4 mmol) of lithium bis(pentafluoroethyl)phosphinate in 15 cm³ of dry diethyl ether are cooled using an ice bath, and 8.0 g (400 mmol) of hydrogen fluoride (HF) are added. The reaction mixture is stirred at 0°C for two hours and then poured into 20 cm³ of ice-water. The ethereal phase is separated off and washed three times with 10 cm³ of water. The ethereal
35 solution is dried using magnesium sulfate and investigated using ¹H and

^{19}F NMR spectroscopy, which confirms the formation of tetrafluorobis-(pentafluoroethyl)phosphoric acid as a complex with diethyl ether.

^{19}F NMR (reference: CCl_3F – internal standard; solvent: CD_3CN film):
-72.13 dm ($^1\text{J}_{\text{P,F}} = 925$ Hz; PF_4); -82.80 quinm ($^4\text{J}_{\text{F,F}} = 7.5$ Hz; $^3\text{J}_{\text{P,F}} = 2.4$ Hz; 2CF_3); -119.06 d,quin,m ($^2\text{J}_{\text{P,F}} = 104$ Hz; $^3\text{J}_{\text{F,F}} = 9.2$ Hz; 2CF_2).
 ^{31}P NMR (reference: 85% H_3PO_4 in D_2O ; solvent: CD_3CN): -149.15 quin,quin,m; $^1\text{J}_{\text{P,F}} = 925$ Hz; $^2\text{J}_{\text{P,F}} = 104$ Hz; $^3\text{J}_{\text{P,F}} = 2.3$ Hz.

Example 2:

1.329 g (4.3 mmol) of lithium bis(pentafluoroethyl)phosphinate in 10.5 cm^3 of dry diethyl carbonate are cooled using an ice bath, and 2.0 g (100 mmol) of hydrogen fluoride (HF) are added. The reaction mixture is stirred at 0°C for half an hour, and the solvent is then removed at 70°C (oil bath) under a vacuum of 1.3 Pa. The residue is investigated using ^1H and ^{19}F NMR spectroscopy, which confirms the formation of tetrafluorobis-(pentafluoroethyl)phosphoric acid as a complex with diethyl carbonate.

^{19}F NMR (reference: CCl_3F – internal standard; solvent: CD_3CN film):
-72.44 d,m ($^1\text{J}_{\text{P,F}} = 925$ Hz; PF_4); -82.93 quin,m ($^4\text{J}_{\text{F,F}} = 7.2$ Hz; 2CF_3); -119.11 d,quin,m ($^2\text{J}_{\text{P,F}} = 104$ Hz; $^3\text{J}_{\text{F,F}} = 9.2$ Hz; 2CF_2).
 ^{31}P NMR (reference: 85% H_3PO_4 in D_2O ; solvent: CD_3CN): -147.58 quin,quin,m; $^1\text{J}_{\text{P,F}} = 925$ Hz; $^2\text{J}_{\text{P,F}} = 104$ Hz.

Example 3:

3.779 g (11.11 mmol) of potassium bis(pentafluoroethyl)phosphinate in 20 cm^3 of dry dioxane are cooled using an ice bath, and 5.0 g (249.9 mmol) of hydrogen fluoride (HF) are added. The reaction mixture is stirred at 0°C for half an hour, and the solvent is then removed at 50°C (oil bath) under a vacuum of 1.3 Pa. The residue, 4.146 g of a white solid material, is investigated using ^{19}F NMR spectroscopy, which confirms the

formation of potassium tetrafluorobis(pentafluoroethyl)phosphate. The yield of $K[(C_2F_5)_2PF_4]$ is 97.2%.

^{19}F NMR (reference: CCl_3F – internal standard; solvent: CD_3CN film):
-71.70 d,m ($^1J_{P,F} = 917$ Hz; PF_4); -82.35 quinm ($^4J_{F,F} = 7.3$ Hz; $^3J_{P,F} = 2.4$ Hz; $2CF_3$); -119.28 d,quin,m ($^2J_{P,F} = 101$ Hz; $^3J_{F,F} = 9.1$ Hz; $^3J_{F,F} = 1.2$ Hz; $2CF_2$).

^{31}P NMR (reference: 85% H_3PO_4 in D_2O ; solvent: CD_3CN): -150.40 quin,quin,m; $^1J_{P,F} = 917$ Hz; $^2J_{P,F} = 101$ Hz; $^3J_{P,F} = 2.4$ Hz.

Example 4:

1.048 g (2.43 mmol) of tetraethylammonium bis(pentafluoroethyl)phosphinate are cooled using an ice bath, and 2.5 g (124.9 mmol) of hydrogen fluoride (HF) are added. The reaction mixture is stirred at $0^\circ C$ for 15 minutes and then poured into 20 cm^3 of ice-water. The precipitate is filtered off, washed twice with 10 cm^3 of water and dried in air, giving 1.028 g of a white solid material. 1H and ^{19}F NMR spectroscopy confirm the formation of tetraethylammonium tetrafluorobis(pentafluoroethyl)phosphate. The yield of $[(C_2H_5)_4N][(C_2F_5)_2PF_4]$ is 89.0% (melting point $201-202^\circ C$).

^{19}F NMR (reference: CCl_3F – internal standard; solvent: CD_3CN): -71.62 dm (PF_4); -82.30 quin,d,t ($2CF_3$); -119.06 d,quin,q ($2CF_2$); $^1J_{P,F} = 916$ Hz; $^2J_{P,F} = 101$ Hz; $^3J_{P,F} = 2.4$ Hz; $^3J_{F,F} = 9.2$ Hz; $^3J_{F,F} = 1.1$ Hz; $^4J_{F,F} = 7.4$ Hz.

1H NMR (reference: TMS; solvent: CD_3CN): 1.21 t,m ($4CH_3$); 3.16 q ($4CH_2$); $^3J_{H,H} = 7.3$ Hz.

^{31}P NMR (reference: 85% H_3PO_4 in D_2O ; solvent: CD_3CN): -150.48 quin,quin,m; $^1J_{P,F} = 916$ Hz; $^2J_{P,F} = 101$ Hz; $^3J_{P,F} = 2.2$ Hz.

Example 5:

4.116 g (9.97 mmol) of 1-ethyl-3-methylimidazolium bis(pentafluoroethyl)phosphinate are cooled using an ice bath, and 5.0 g (250 mmol) of hydrogen fluoride (HF) are added. The reaction mixture is stirred at $0^\circ C$ for 15

minutes and then poured into 20 cm³ of ice-water. The precipitate is filtered off, washed twice with 10 cm³ of water and dried in air, giving 4.208 g of a white solid material. ¹H, ³¹P and ¹⁹F NMR spectroscopy confirm the formation of 1-ethyl-3-methylimidazolium tetrafluorobis(pentafluoroethyl)-phosphate. The yield is 92.0% (melting point 60°C).

¹⁹F NMR (reference: CCl₃F – internal standard; solvent: CD₃CN): -71.40 d,m (¹J_{P,F} = 914 Hz; PF₄); -82.18 quin,d,t (⁴J_{F,F} = 7.4 Hz, ³J_{P,F} = 2.4 Hz, ³J_{F,F} = 1 Hz; 2CF₃); -118.80 d,quin,q (²J_{P,F} = 101 Hz, ³J_{F,F} = 9.1 Hz; 2CF₂).
¹H NMR (reference: TMS; solvent: CD₃CN): 1.47 t (³J_{H,H} = 7.3 Hz; CH₃); 3.82 s (CH₃); 4.17 q (CH₂); 7.32 d,d (³J_{H,H} = 2.3 Hz; ⁴J_{H,H} = 1.7 Hz 1H); 7.37 d,d (1H); 8.38 brs (1H).
³¹P NMR (reference: 85% H₃PO₄ in D₂O; solvent: CD₃CN): -150.36 quin,quin,m; ¹J_{P,F} = 914 Hz, ²J_{P,F} = 101 Hz.

Example 6:

7.079 g (13.29 mmol) of tributylethylphosphonium bis(pentafluoroethyl)-phosphinate are cooled using an ice bath, and 10.0 g (500 mmol) of hydrogen fluoride (HF) are added. The reaction mixture is stirred at 0°C for 15 minutes and then poured into 20 cm³ of ice-water. The precipitate is filtered off, washed twice with 10 cm³ of water and dried in air, giving 7.324 g of a white solid material. ¹H, ³¹P and ¹⁹F NMR spectroscopy confirm the formation of tributylethylphosphonium tetrafluorobis(pentafluoroethyl)phosphate. The yield is 95.0% (melting point 76°C).

¹⁹F NMR (reference: CCl₃F – internal standard; solvent: CD₃CN): -71.40 d,m (¹J_{P,H} = 914 Hz; PF₄); -82.18 quin,d,t (⁴J_{F,F} = 7.2 Hz; ³J_{P,F} = 2.4 Hz; ³J_{F,F} = 1 Hz; 2CF₃); -118.80 d,quin,q (²J_{P,F} = 101 Hz; ³J_{F,F} = 8.9 Hz; 2CF₂).
¹H NMR (reference: TMS; solvent: CD₃CN): 0.96 t (3CH₃); 1.19 d,t (³J_{H,P} = 18.2 Hz; ³J_{H,H} = 7.6 Hz; CH₃); 1.39-1.59 m (12H); 1.92-2.16 m (8H).

^{31}P NMR (reference: 85% H_3PO_4 in D_2O ; solvent: CD_3CN): 34.77 m;
-150.36 quin,quin,m; $^1\text{J}_{\text{P,F}} = 914$ Hz; $^2\text{J}_{\text{P,F}} = 101$ Hz.

Example 7:

5 0.699 g (1.53 mmol) of 1-ethyl-3-methylimidazolium bis(pentafluoroethyl)-
tetrafluorophosphate and 0.290 g (2.17 mmol) of aluminium trichloride are
mixed with one another in a Teflon flask at room temperature and under a
dry nitrogen atmosphere. The mixture becomes viscous, and a slight rise
10 in the temperature is observed. After stirring for two hours, the flask is
evacuated (0.1 mbar), and the volatile product is collected in a flask cooled
using liquid nitrogen, giving 0.439 g of bis(pentafluoroethyl)trifluorophos-
phorane. The yield is 88%.

15 ^{19}F NMR (reference: CCl_3F – internal standard; solvent: CD_3CN film):
-49.85 d,m ($^1\text{J}_{\text{P,F}} = 1143$ Hz; PF_4); -81.09 brs (2CF_3); -116.78 d,m
($^2\text{J}_{\text{P,F}} = 127$ Hz; 2CF_2).
 ^{31}P NMR (reference: 85% H_3PO_4 in D_2O ; solvent: CD_3CN): -39.05 q,quin,m
20 $^1\text{J}_{\text{P,F}} = 1143$ Hz; $^2\text{J}_{\text{P,F}} = 127$ Hz.

Example 8:

0.883 g (1.53 mmol) of tributylethylphosphonium bis(pentafluoroethyl)-
25 tetrafluorophosphate and 0.290 g (2.10 mmol) of aluminium trichloride are
mixed with one another in a Teflon flask at room temperature and under a
dry nitrogen atmosphere. The mixture becomes viscous, and a slight rise
in the temperature is observed; after 30 minutes, the mixture becomes
solid. The flask is evacuated (0.1 mbar) and heated until the mixture melts
30 (about 50°C), and the volatile product is collected in a flask cooled using
liquid nitrogen, giving 0.305 g of bis(pentafluoroethyl)trifluorophosphorane.
The yield is 61%.

^{19}F NMR (reference: CCl_3F – internal standard; solvent: CD_3CN film):

-49.85 d,m ($^1\text{J}_{\text{P,F}} = 1143 \text{ Hz}$; PF_4); -81.09 brs (2CF_3); -116.78 d,m ($^2\text{J}_{\text{P,F}} = 127 \text{ Hz}$; 2CF_2).

^{31}P NMR (reference: 85% H_3PO_4 in D_2O ; solvent: CD_3CN): -39.05 q,quin,m

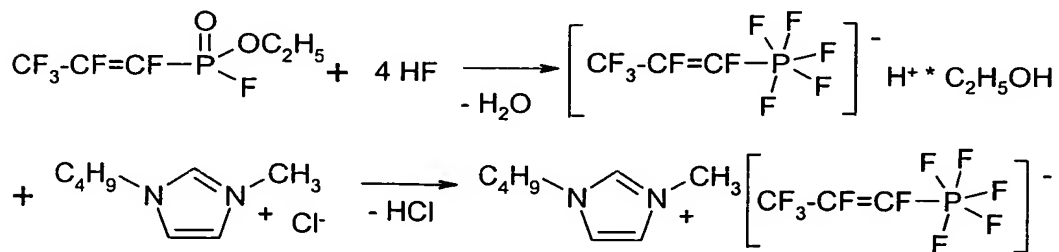
$^1\text{J}_{\text{P,F}} = 1143 \text{ Hz}$; $^2\text{J}_{\text{P,F}} = 127 \text{ Hz}$.

Example 9:

1.35 g (6.228 mmol) of antimony pentafluoride are introduced into a Teflon flask, and 2.40 g (4.164 mmol) of tributylethylphosphonium bis(pentafluoroethyl)tetrafluorophosphate (prepared as described in Example 6) are added while the reaction mixture is stirred using a magnetic stirrer. The mixture becomes liquid and is heated at 100°C for 30 minutes. The volatile product is condensed in a Teflon trap cooled using a dry ice/ethanol mixture. After the cold trap has been warmed to room temperature, 1.31 g of liquid bis(pentafluoroethyl)trifluorophosphorane are obtained. The yield of $(\text{C}_2\text{F}_5)_2\text{PF}_3$ is 96.5%, based on the tributylethylphosphonium bis(pentafluoroethyl)tetrafluorophosphate. The NMR data agree with those obtained for the compound in Example 8.

The residue in the reaction flask is a viscous liquid – tributylethylphosphonium hexafluoroantimonate as a complex with excess SbF_5 (acidic ionic liquid): $[(\text{C}_4\text{H}_9)_3(\text{C}_2\text{H}_5)\text{P}]^+ \text{SbF}_6^- 0.50 \text{ SbF}_5$.

Example 10:



1.023 g (51.15 mmol) of hydrogen fluoride (HF) are cooled to -20°C using an ethanol bath, and 0.934 g (3.86 mmol) of ethyl perfluoroprop-1-enyl-

fluorophosphonate is added. The reaction mixture is stirred at 0°C. The reaction mixture and 0.674 g (3.86 mmol) of 1-butyl-3-methylimidazolium chloride are then mixed with one another at -20°C in a Teflon flask. After the mixture has been stirred at room temperature for 15 minutes, the flask is evacuated and held for one hour under a reduced pressure of 13.33 Pa and at a bath temperature of 50°C, giving 1.44 g of 1-butyl-3-methylimidazolium perfluoroprop-1-enylpentafluorophosphate. The yield is 94%.

¹⁹F NMR (reference: CCl₃F – internal standard; solvent: CD₃CN): -61.39 ddd (4F); ¹J_{F,P} = 784 Hz; ²J_{F,F} = 48 Hz; ³J_{F,F} = 14 Hz; -66.72 dd (3F, CF₃); ⁴J_{F,F} = 23 Hz, ³J_{F,F} = 11 Hz; -71.51 dquin (1F); ¹J_{F,P} = 731 Hz; ²J_{F,F} = 48 Hz; -145.2 ddq (1F); ²J_{F,P} = 100 Hz, ³J_{F,F} = 132 Hz; ⁴J_{F,F} = 23 Hz; -169.5 dm (1F); ³J_{F,F} = 132 Hz.

¹H NMR (reference: TMS; solvent: CD₃CN): 0.93 t (3H, CH₃); ³J_{H,H} = 7.4 Hz; 1.32 m (2H, CH₂); 1.80 m (2H, CH₂); 3.81 s (3H, CH₃); 4.11 t (2H, CH₂); ³J_{H,H} = 7.2 Hz; 7.32 m (1H, CH); 7.35 m (1H, CH); 8.42 br. s (1H, CH).

³¹P NMR (reference: 85% H₃PO₄; solvent: CD₃CN): -149.2 dquindd; ¹J_{P,F} = 783 Hz, ¹J_{P,F} = 731 Hz; ²J_{P,F} = 102 Hz; ³J_{P,F} = 9 Hz.

NMR spectra of perfluoroprop-1-enylpentafluorophosphoric acid:

¹⁹F NMR (reference: CCl₃F; solvent HF, lock solvent: CD₃CN film; -15°C): -62.1 br.d (5F); ¹J_{P,F} = 684 Hz; -67.73 dd (3F, CF₃); ⁴J_{F,F} = 23 Hz; ³J_{F,F} = 11 Hz; -149.3 ddq (1F); ²J_{F,P} = 109 Hz, ³J_{F,F} = 133 Hz; ⁴J_{F,F} = 23 Hz; -165.8 dm (1F); ³J_{F,F} = 133 Hz; ²J_{F,F} = 10 Hz; ³J_{F,P} = 10 Hz.

³¹P NMR (reference: 85% H₃PO₄; solvent: HF; lock solvent: CD₃CN film; -15°C): -147.6 br.s.

Example 11:

1.2 g of hydrogen fluoride (HF) are cooled using an ice bath, and 0.80 g (2.5 mmol) of methyl bis(pentafluoroethyl)phosphinate, (C₂F₅)₂P(O)OCH₃, is added. The reaction mixture is stirred at 0°C for half an hour. The ex-

cess HF is removed by flushing with nitrogen, and the residue is dried under a vacuum of 1.3 Pa, giving 0.87 g of tetrafluorobis(pentafluoroethyl)-phosphoric acid, $\text{H}^+[(\text{C}_2\text{F}_5)_2\text{PF}_4]^-$, as a complex with methanol.

5 ^{19}F NMR (reference: CCl_3F – internal standard; lock: CD_3CN film): -73.32 d,m ($^1\text{J}_{\text{P,F}} = 933$ Hz; PF_4); -83.97 m (2CF_3); -119.68 d,quin ($^2\text{J}_{\text{P,F}} = 107$ Hz; $^3\text{J}_{\text{F,F}} = 8.3$ Hz; 2CF_2).

10 ^1H NMR (reference: TMS; lock: CD_3CN film): 2.86 br.s, 7.27 br.s.

^{31}P NMR (reference: 85% H_3PO_4 in D_2O ; lock: CD_3CN film): -148.8 quin,quin; $^1\text{J}_{\text{P,F}} = 932$ Hz; $^2\text{J}_{\text{P,F}} = 107$ Hz.

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